Event Shape Analysis of Multihadronic Final States in Deep Inelastic Rapidity Gap events at HERA

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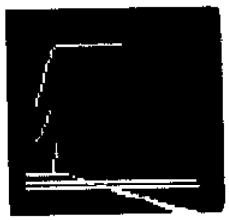
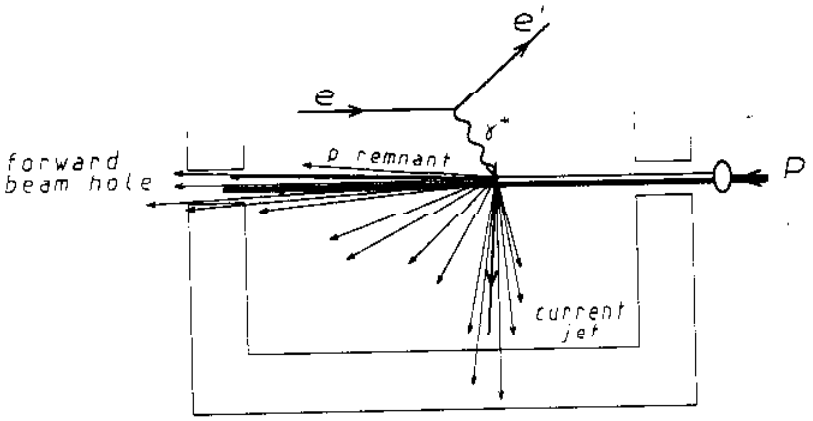
for the **ZEUS Collaboration**



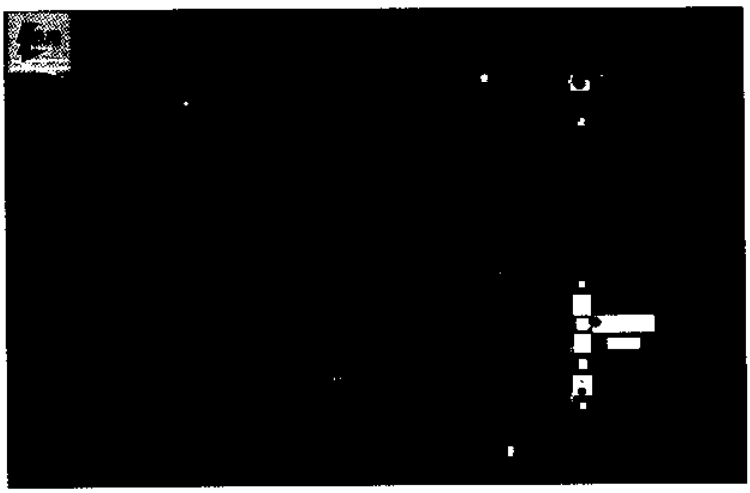
- **Large forward rapidity gap events.**
- **Event topology in the c.m. frame of the colliding particles.**
- **Event shape studies in e^+e^- annihilation: Jet structure.**
- **Jet structure in DIS LRG events.**
- **Comparison e^+e^- data - ZEUS DIS LRG data.**
- **Comparison diffractive MC models - ZEUS DIS LRG data.**

HERA: Deep Inelastic ep Scattering (DIS) at $\sqrt{s} \sim 300\ GeV$

Standard Neutral Current DIS process



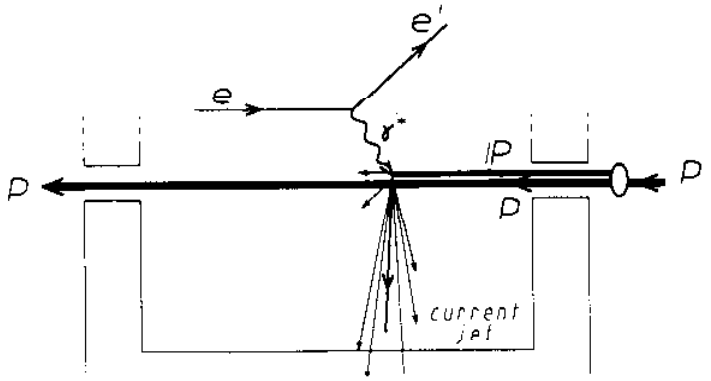
DIS large forward rapidity gap events



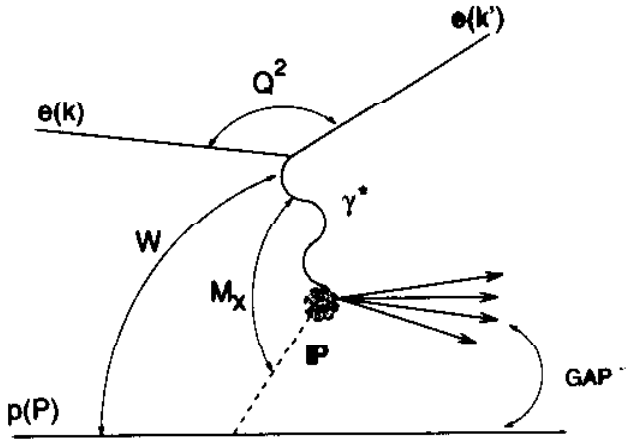
Diffractive Multihadronic final states:

- **No proton remnant in the forward direction: The proton remains intact after the interaction.**
- **Hadronic activity.**
- **No energy flow between the hadronic final state and the forward direction.**

Interpretation: **Exchange of colorless object called** *Pomeron*



Kinematics



$Q^2 = -(k - k')^2$ square of 4-momentum transfer

$W^2 = ((k - k') + P)^2$ square of c.m energy γ^*–proton frame

$M_X^2 = (\Sigma E)^2 - (\Sigma p_x)^2 - (\Sigma p_y)^2 - (\Sigma p_z)^2$

Mass of the multihadronic final state

If we assume diffractive scattering caused by $\mathbb{P}$ exchange:

$M_X^2 = ((k - k') + \mathbb{P})^2$ square of c.m energy $\gamma^* - \mathbb{P}$ system

$x_{\mathbb{P}} = \frac{Q^2 + M_X^2}{Q^2 + W^2}$ fraction of proton's momentum carried by the $\mathbb{P}$

Since we do not measure the scattered proton, we assume the pomeron to be collinear with the initial proton:

$$\mathbb{P}^\mu = x_{\mathbb{P}} \cdot P^\mu$$

DIS LRG event selection

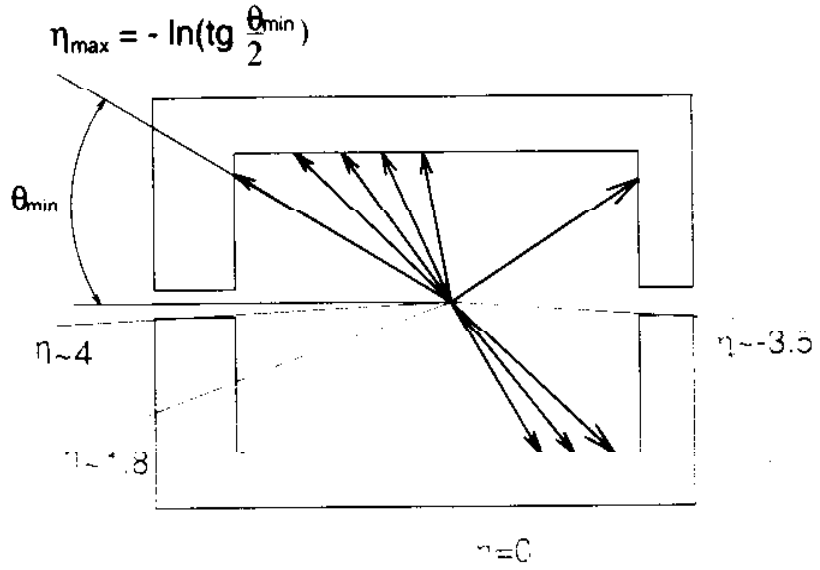
- $Q^2 > 5$ ***GeV*^{2}**
- $160 < W < 250$ ***GeV***
- $7 < M_X < 25$ ***GeV***
- More than three particles
- $\eta_{max} < 1.8$

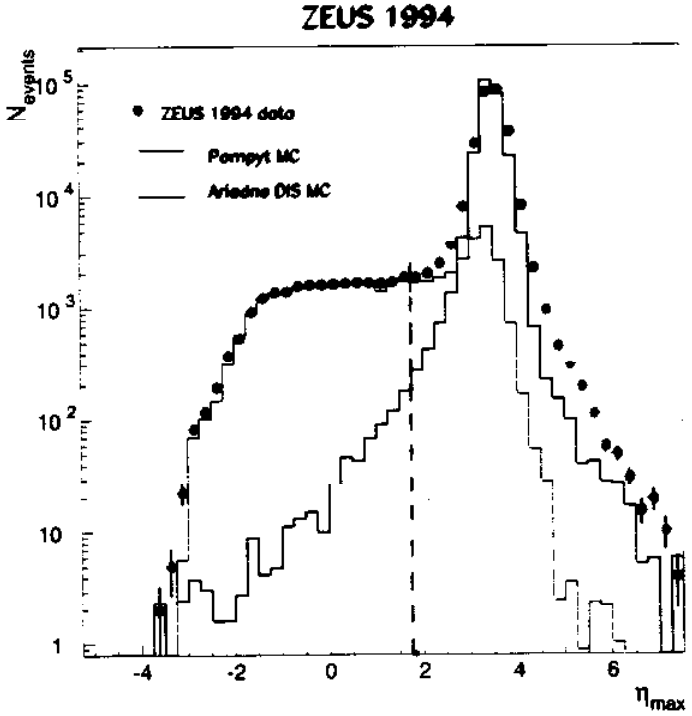
$N_{part} > 3$ and $M_X > 7$ *GeV* ensure sufficient hadronic activity.

$W > 160$ *GeV* and $M_X < 25$ *GeV* are dictated by the contamination from non-diffractive DIS.

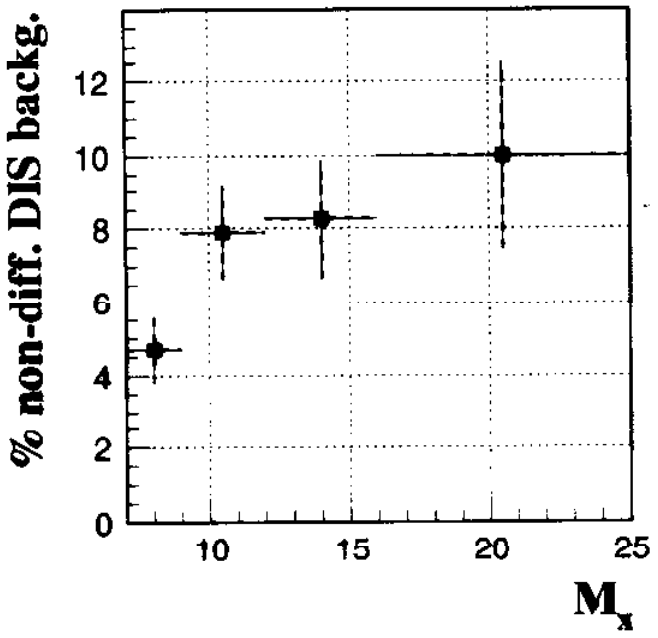
$\eta_{max} < 1.8$ to suppress non-diffractive DIS background.

η_{max} : pseudorapidity of the most forward particle.





The remaining non-diffractive DIS contamination after $\eta_{max} < 1.8$ will be subtracted using MC simulation.



Event shape analysis

Motivation:

What:

- **The nature of the** *Pomeron* **is still far from being clear: partonic structure?, gluon content? ...**
- **Get deeper understanding of the** basic processes **involved in deep inelastic diffractive scattering.**

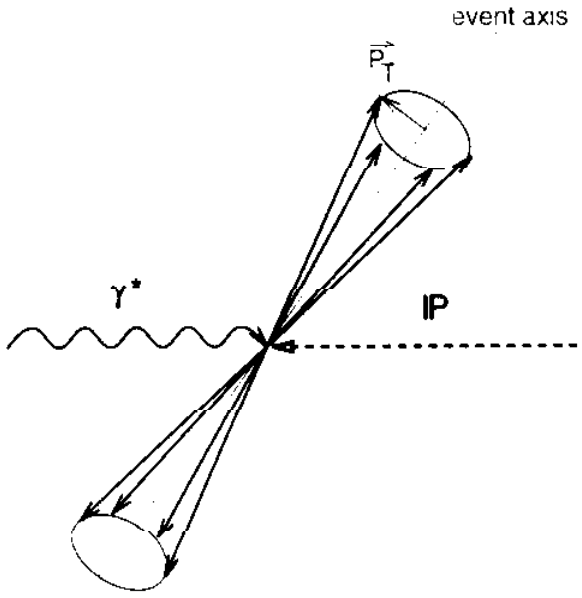
How:

- **Study the** evolution with M_X **of the** event shapes **of diffractive multihadronic final states in $\gamma^* I\!P$ frame.**
- **The** jet structure **is established by studying this energy dependence.**

Why:

- **The** range of mass M_X **is** appropriate **for an analysis of the topological characteristics of the final states.**
- **The event shape variables are sensitive to higher order parton diagrams in pQCD.**
- **A** similar study in e^+e^- **led to the evidence of jet production.**

Topology of the event in the $\gamma^* I\!P$ frame:



- event axis ($\vec{n}_S$): **that direction which minimizes the $\Sigma\, p_T^2$ of the event.**

- Sphericity:

$$S = \frac{3}{2} \min_{\vec{n}} \frac{\Sigma\, p_{Ti}^2}{\Sigma\, p_i^2} \qquad (\vec{n} = \vec{n}_S)$$

$\Rightarrow$ S gives the topology of the event:

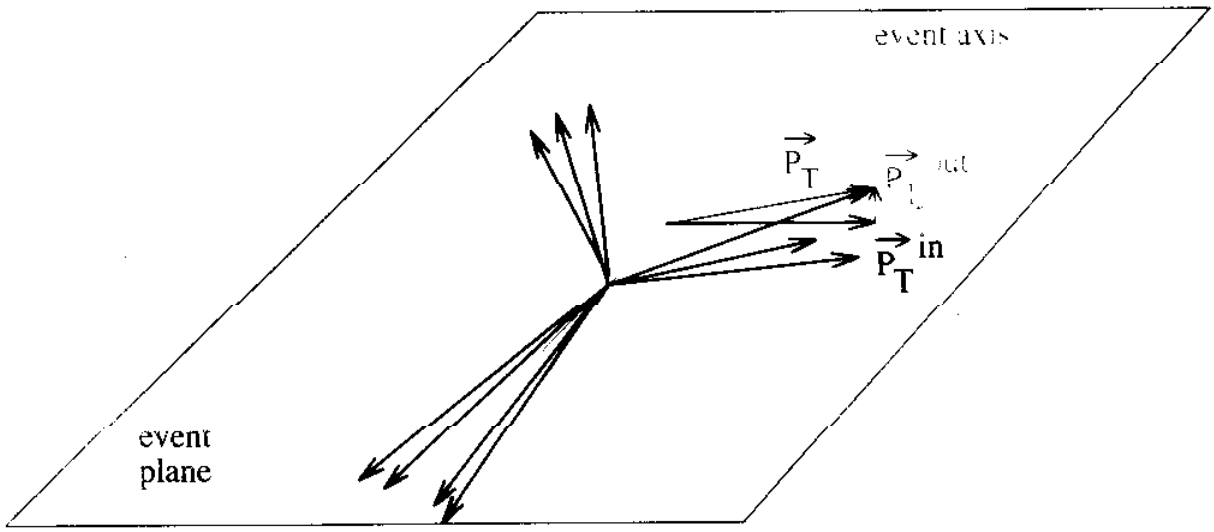
2-jet-like events: $S \to 0$
spherical events: $S \to 1$

- Mean squared transverse momentum **w.r.t. $\vec{n}_S$:**

$$p_T^2 = \frac{\Sigma\, p_T^2}{N}$$

$\Rightarrow \langle p_T^2 \rangle$ is sensitive to three jet structure

Three-jet final state topology



• Mean squared transverse momentum in **and** out **of the event plane:** $p_{T\,in}^2 + p_{T\,out}^2 = \langle \boldsymbol{p_T^2} \rangle$

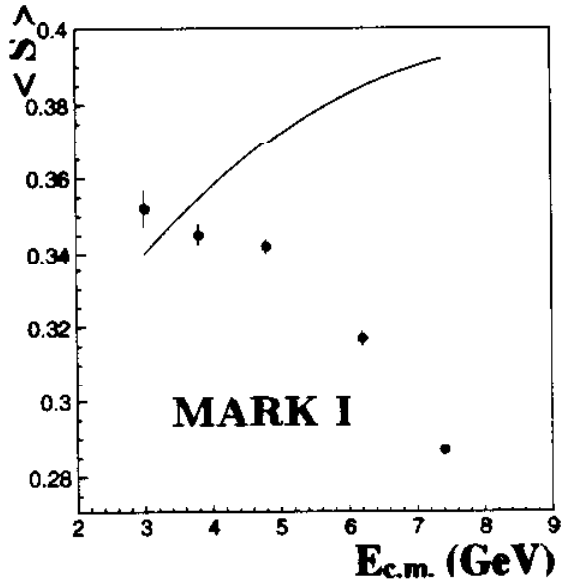
For a three-jet final state:

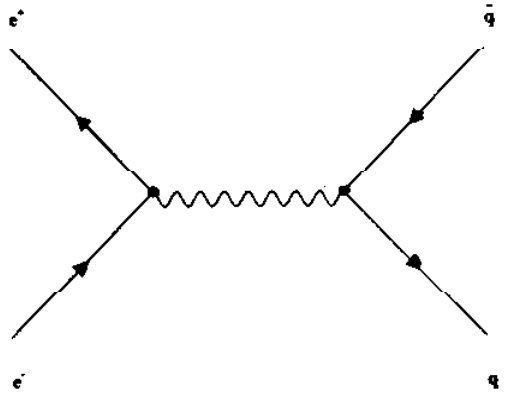
- **Non negligible $\langle p_T^2 \rangle$ w.r.t the event axis.**
- **Since the three jets must be in the event plane, $\langle p_{T\,out}^2 \rangle$ should be small.**

Event shape studies in e^+e^- annihilation

1. SPEAR (SLAC) 1975 **($3.0 < \sqrt{s} < 7.4\ GeV$):**
   $\langle S \rangle$ decreases with increasing $\sqrt{s}$ in contrast to pure phase-space expectations: Clear sign of collimation.

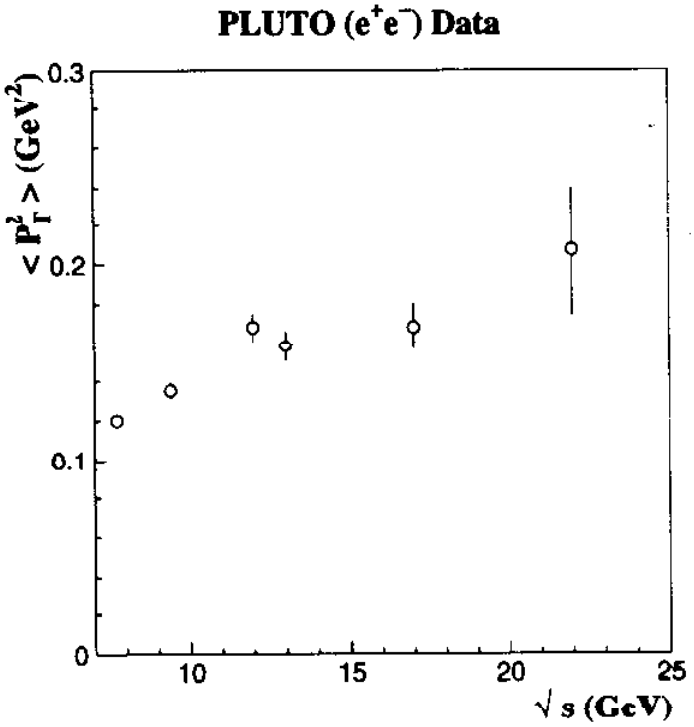
$\Longrightarrow$ FIRST EVIDENCE FOR JET PRODUCTION in e^+e^-

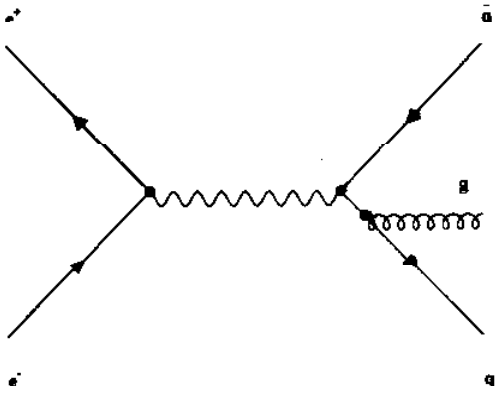




2. PETRA (DESY) 1979 **($7.7 < \sqrt{s} < 31.6$ GeV):**
$\langle p_T^2 \rangle$ increases with increasing $\sqrt{s}$ while
$\langle p_{T\,out}^2 \rangle$ remains limited: The events become planar.

FIRST EVIDENCE FOR THREE JET PRODUCTION
in e^+e^- by hard non-collinear gluon bremsstrahlung





Event shape studies in DIS LRG events

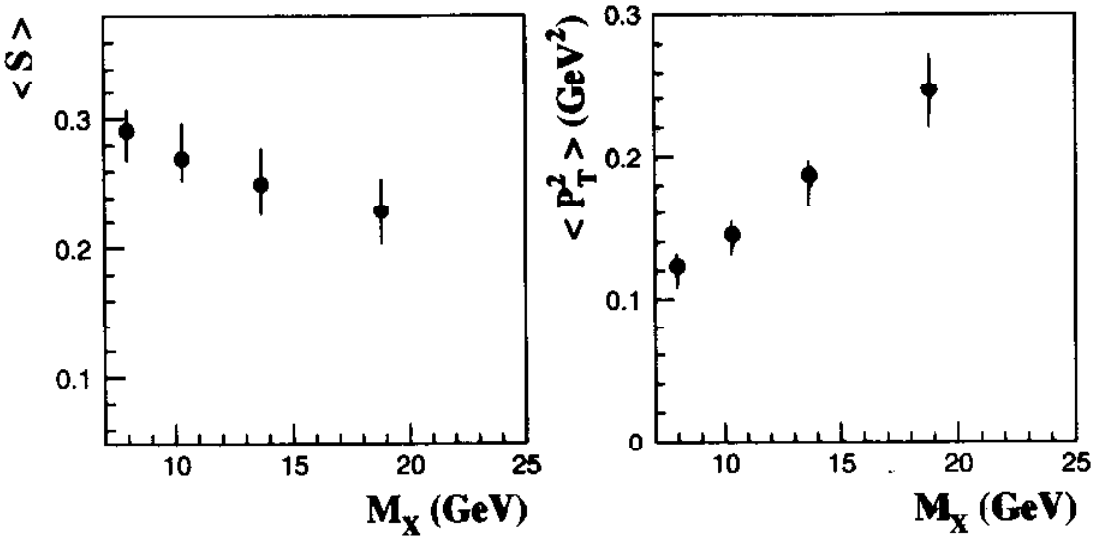
The jet structure is established by studying the dependence of the mean values of the event shape variables on the c.m. energy in the $\gamma^* I\!P$ frame

⇒ **First, we subtract the remaining non-diffractive DIS background after the cut $\eta_{max} < 1.8$, using a standard DIS MC.**

Correction to the hadron level

⇒ **Using a diffractive MC, we correct the mean values to the hadron level (before detector) to the true region:**

$$Q^2 > 5 \ GeV^2$$
$$160 < W < 250 \ GeV$$
$$7 < M_X < 25 \ GeV$$
$$\eta_{max} < 1.8$$

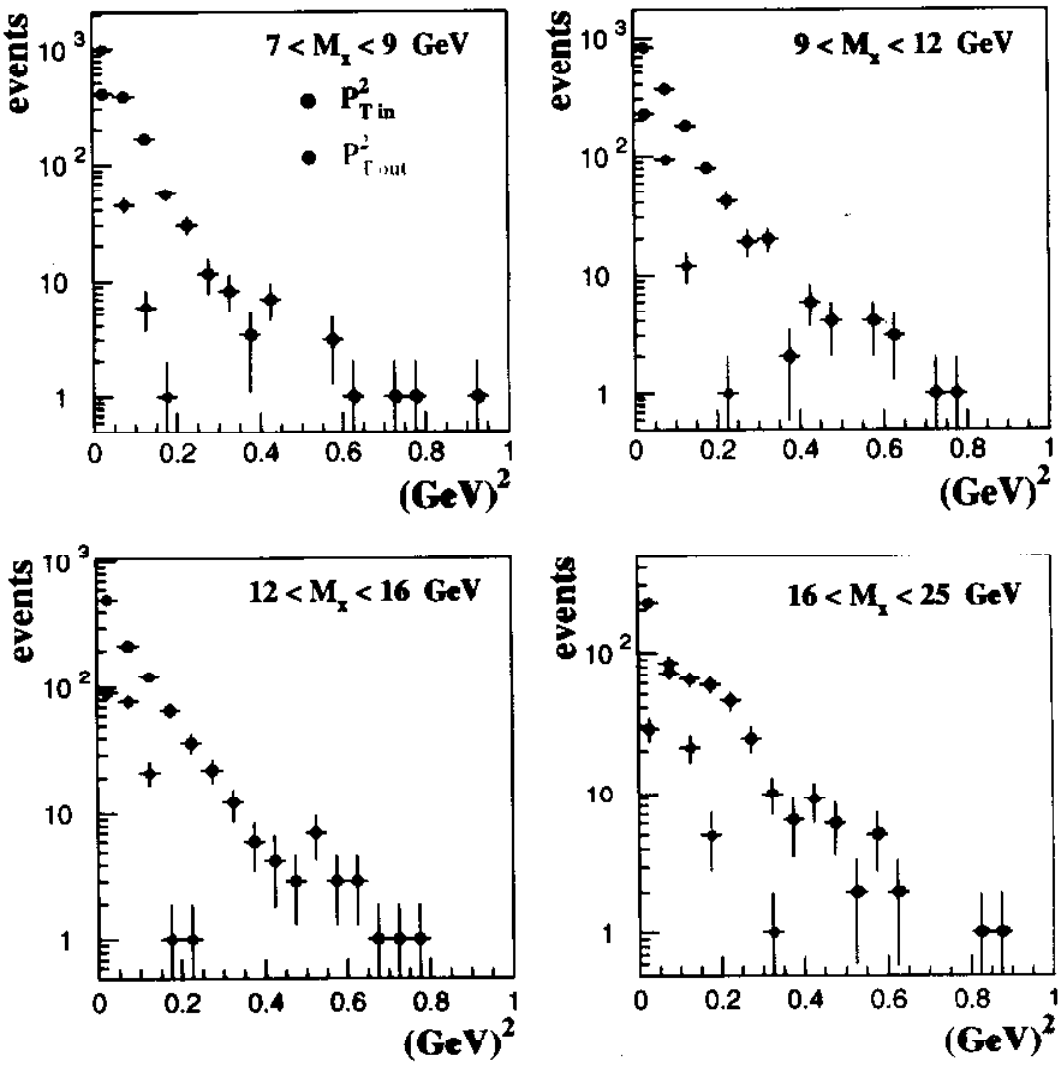


● ZEUS 94 Preliminary

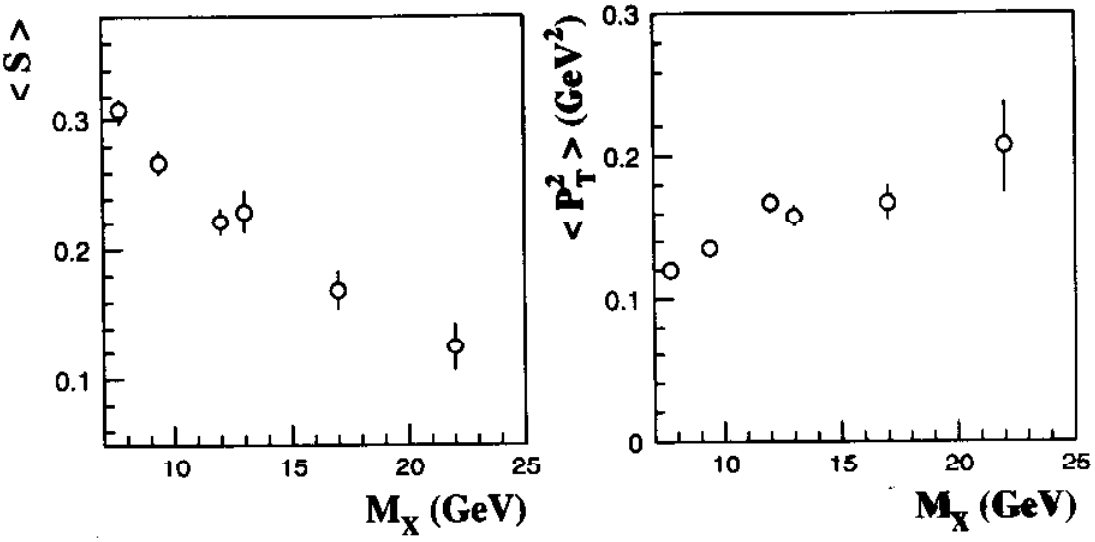
ZEUS data:

- $\langle S \rangle$ decreases with increasing M_X : Collimation, jet formation
- Strong rise in $\langle p_T^2 \rangle$ and $\langle p_{T\,out}^2 \rangle$ limited: The events become planar, three jet formation.

ZEUS 1994 DIS LRG events (preliminary)



(p_{Tin}^2) increases with increasing M_X while $(p_{T\,out}^2)$ remains limited: $\Rightarrow$ The events become planar.



○ PLUTO (e^+e^-)

Comparison ZEUS-PLUTO:

- Diffractive DIS less collimated than e^+e^- at high energies
- Stronger rise in $\langle p_T^2 \rangle$ in diffractive DIS:
  $\Rightarrow$ Additional mechanism to hard gluon bremsstrahlung for three jet formation.

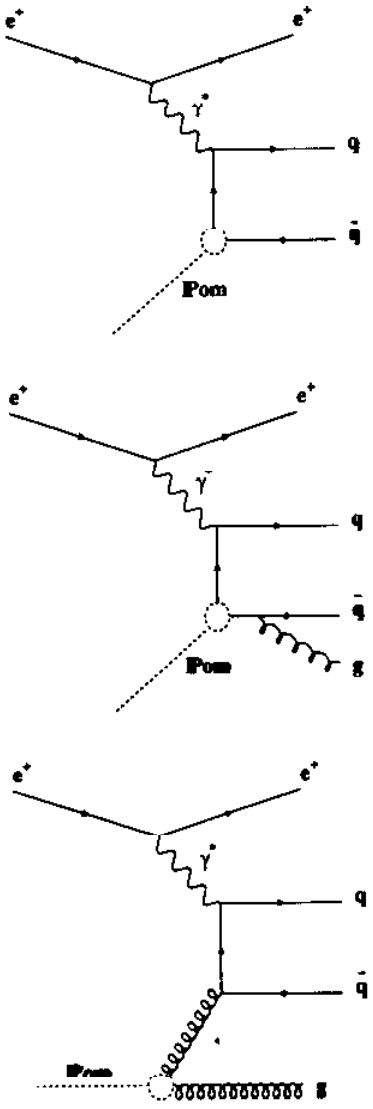
Factorisable Models for Pomeron induced reactions

- Basic mechanism:
  Pomeron emission by the proton and subsequent hard interaction between the γ^* and one of the partons from the pomeron.
- Pomeron structure:

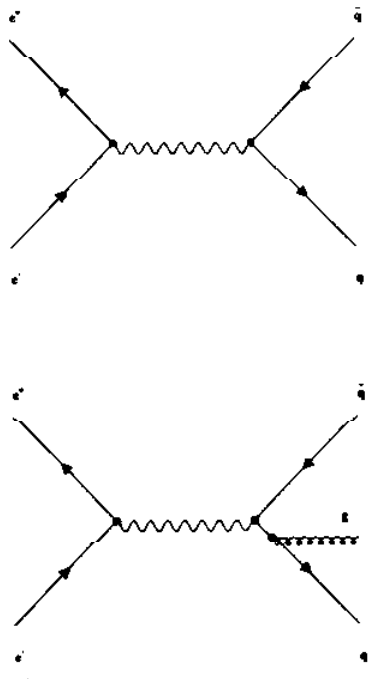
1. Ingelman-Schlein approach:

Partonic densities **(quarks and/or gluons) in the pomeron.**

$\Rightarrow$ RAPGAP MC



e^+e^-



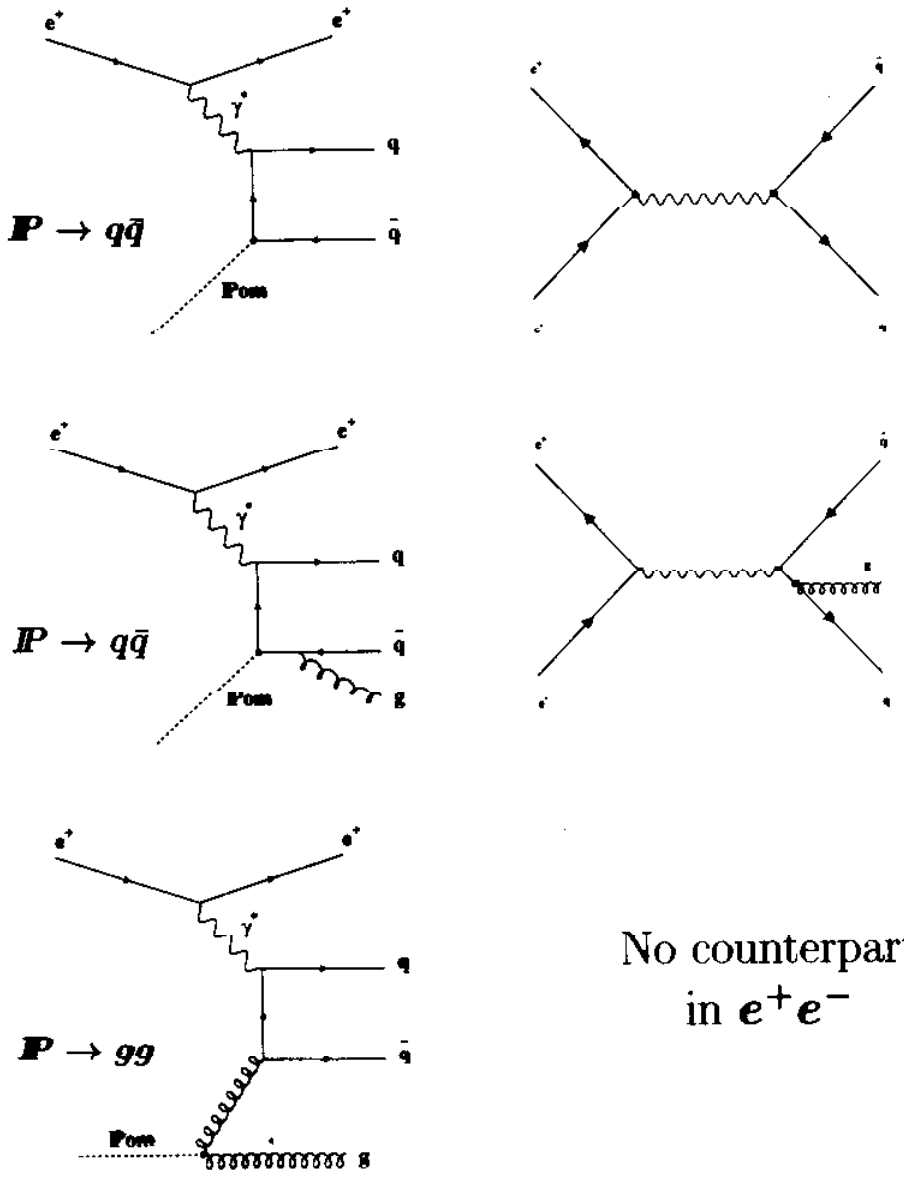
No counterpart in e^+e^-

2. Vermaseren-Barreiro-Labarga-Ynduráin approach:

- **The Pomeron has no structure.**
- Pointlike coupling **of the pomeron to quarks and gluons.**
- **The simplest model one can think of.**

$\Rightarrow$ VBLY MC

e^+e^-



No counterpart in e^+e^-

The relative coupling **of the** *Pomeron* **to gluons, $\alpha\cdot(I\!P \to gg)$, or quarks, $(1\text{-}\alpha)(I\!P \to q\bar{q})$ is a free parameter in the VBLY model:**

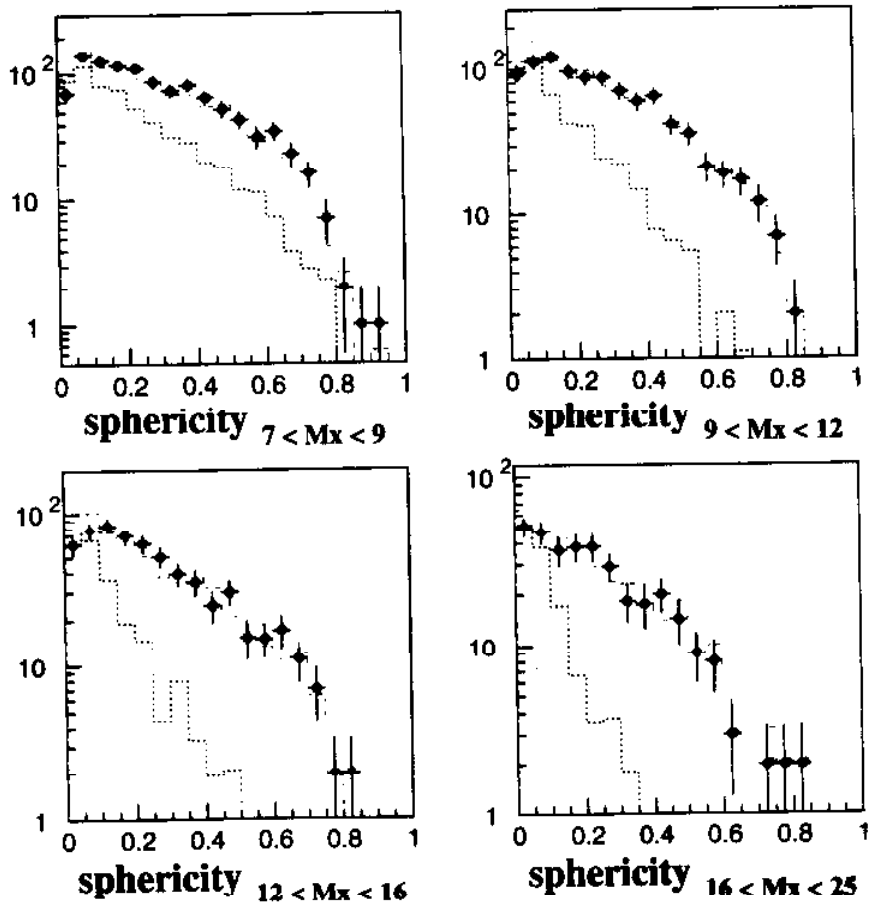
⇒ **α must be determined from a** fit to a set of hadronic data distributions: ⇒ $\alpha = 0.53 \pm 0.06$

⇒ **After the fit, around 50% of the final states come from $I\!P \to gg$ and 50% from $I\!P \to q\bar{q}$.**

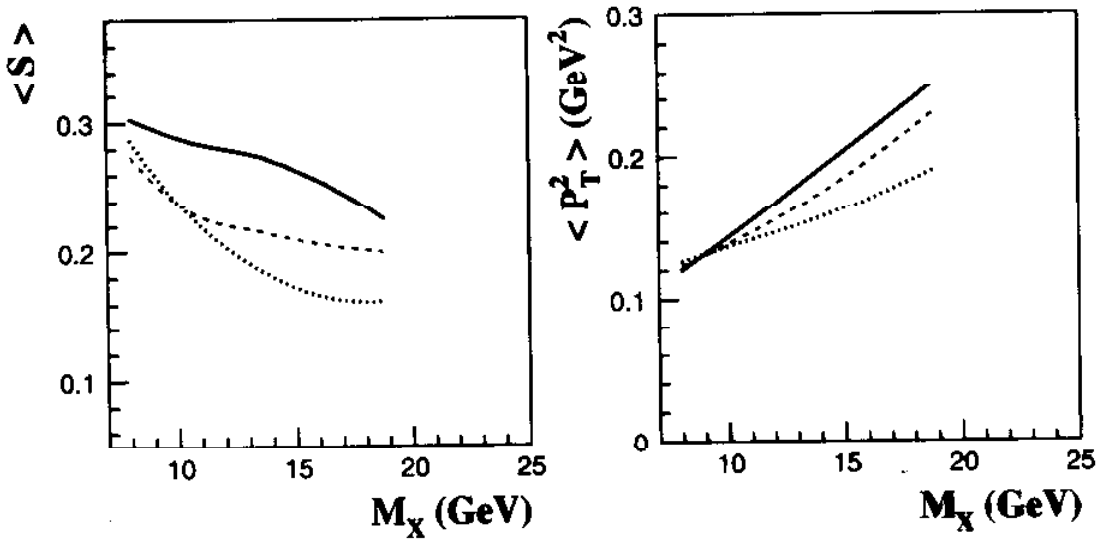
..... $(1-\alpha)(I\!P \to q\bar{q})$

- - - - $\alpha\cdot(I\!P \to gg)+(1-\alpha)(I\!P \to q\bar{q})$

● **ZEUS 94 preliminary**



... $I\!P \to gg$ ...



Comparison ZEUS-MC Models:

- MC only quarks in $I\!P$: Similar to e^+e^-
- MC quarks and gluons in $I\!P$:Closer to data(no tuning attempted)
- MC pointlike coupling of $I\!P$ to quarks and gluons:
  Can describe the data using the appropriate proportion of
  $I\!P \to q\bar{q}$ and $I\!P \to gg$

Conclusions

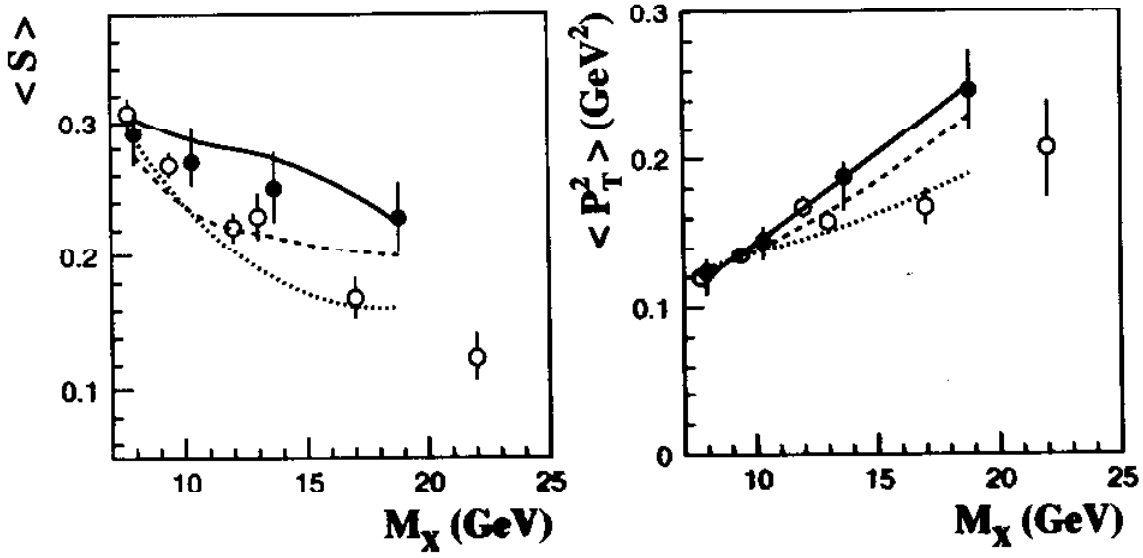
- **We have investigated in LRG events the** dependence of **classical jet variables like** mean sphericity **and** mean squared transverse momentum **w.r.t. the event axis,** on M_X **, the c.m. energy in the $\gamma^* I\!P$ collision.**

- **With increasing M_X the events become planar.** $\langle S \rangle$ falls off less sharply than in e^+e^- annihilation.

- Broadening effects **(strong rise in $\langle p_T^2 \rangle$)** stronger than in e^+e^- .

- Additional mechanism to hard gluon bremsstrahlung needed.

- **In the framework of the MC models discussed, a $I\!P$ coupling also to gluons is needed in order to describe the data.**



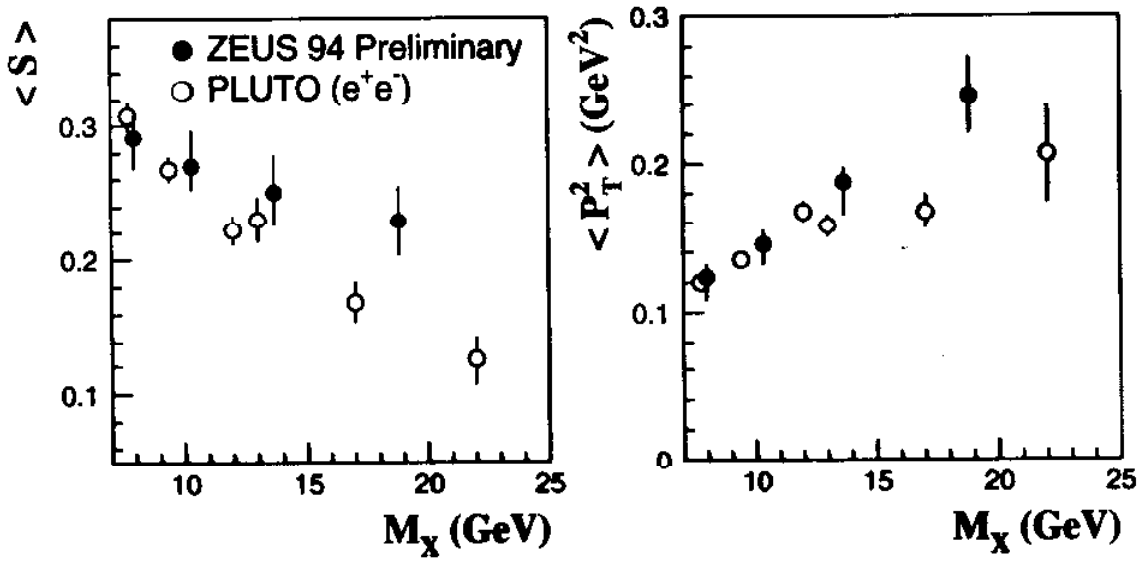
● ZEUS 94 Preliminary

○ PLUTO (e^+e^-)

—— VBLY qq & gg couplings

- - - - - - RAPGAP quarks+gluons

..... RAPGAP only quarks


ZEUS 94 Preliminary
PLUTO (e^+e^-)
$\langle S \rangle$
$\langle P_T^2 \rangle$ (GeV^2)
M_X (GeV)
M_X (GeV)

No counterpart
in e^+e^-
γ^*
e^+
e^-
p
$\bar{p}$
from
M^X (GeV)
$\langle z \rangle$
$\langle p_T^2 \rangle$ (GeV^2)